AD/A-003 484

A COMPARISON OF THE LASA-NORSAR SHORT PERIOD ARRAYS

A. C. Chang

Teledyne Geotech

Prepared for:

Defense Advanced Research Projects Agency
Air Force Technical Applications Center

12 April 1974

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER SDAC-TR-74-5	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A-003484
4. TITLE (and Subtitle) A COMPARISON OF THE LASA-NORSAR SHORT PERIOD ARRAYS		5. TYPE OF REPORT & PERIOD COVERED Technical
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Chang, A. C.		8. CONTRACT OR GRANT NUMBER(s) F08606-74-C-0006
9. PERFORMING ORGANIZATION NAME AND ADDRESS Teledyne Geotech 314 Montgomery Street Alexandria, Virginia 22314		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency Nuclear Monitoring Research Office 1400 Wilson Blvd.-Arlington, Va. 22209		12. REPORT DATE 12 April 1974
		13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) VELA Seismological Center 312 Montgomery Street Alexandria, Virginia 22314		15. SECURITY CLASS (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

LASA	Event Processor
NORSAR	Long Time Averages
Detection Processor	Short Time Averages

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study compares the LASA and NORSAR short-period arrays in terms of their detection processing systems and their event summaries, for data recorded during a period of 40 days from 15 February to 25 March 1972. An overview of the worldwide surveillance performance of the combined LASA-NORSAR systems is also given.

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Either LASA or NORSAR confirmed 73% of the events on the NOAA PDE (Preliminary Detection of Epicenters) list over the data period, and 37% were confirmed by both arrays. The LASA alone reported 56% of the events on PDE list, and NORSAR alone reported 53%.

A direct comparison of LASA and NORSAR Event Summaries shows that 72% of the NORSAR published events are within LASA's surveillance range. Of these in-the-range events, 70% were confirmed by LASA. Of the unconfirmed events 11% were due to system failures, and 7% were unconfirmed by DP. Similarly, 78% of the LASA published events were within NORSAR's surveillance range. Among these in-the-range events, 38% were confirmed by NORSAR. Of the unconfirmed events 5% were due to system failures, and 45% were unconfirmed by DP. The high percentage of NORSAR DP unconfirmed events is due partly to the high background noise of the array.

Although we do not estimate the detection thresholds of the arrays in this report, we note that the average noise on the LASA beams is about a factor of two lower than that of NORSAR. Therefore, LASA's detection threshold would be ~0.3 magnitude units lower than NORSAR's, if average signal losses were the same at both sites.

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A COMPARISON OF THE LASA AND NORSAR SHORT PERIOD ARRAYS

SEISMIC DATA ANALYSIS CENTER REPORT NO.: SDAC-TR-74-5

AFTAC Project No.:	VELA VT/4709
Project Title:	Seismic Data Analysis Center
ARPA Order No.:	1620
ARPA Program Code No.:	3F10
Name of Contractor:	TELEDYNE GEOTECH
Contract No.:	F08606-74-C-0006
Date of Contract:	01 July 1973
Amount of Contract:	$2,152,172
Contract Expiration Date:	30 June 1974
Project Manager:	Royal A. Hartenberger (703) 836-3882

P. O. Box 334, Alexandria, Virginia 22314

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LIST OF ABBREVIATIONS

SBS	=	Subarray Beam Set
SAB	=	Subarray Beams
SPS	=	Special Processing System
SS	=	Selected Surveillance
GS	=	General Surveillance
STA	=	Short Time Average
LTA	=	Long Time Average
Q/Q'	=	Threshold logic parameter
P	=	Spatial Coherency Parameter
ΔU	=	Spatial Coherency Parameter
DP	=	Detection Processor
EP	=	Event Processor
mμ/qu	=	Millimicrons per quantum unit
NM/qu	=	Nanometers per quantum unit

1. INTRODUCTION

There are similarities between LASA and NORSAR in their instrumentation, array size and design, and data processing hardware and software. Currently they are both operating in continuous 24-hour surveillance of seismic activities. Teledyne Geotech has operated SAAC since 15 January 1971, and publication of the daily Event Summary has been performed since 1 February 1971. The Royal Norwegian Council for Scientific and Industrial Research took over the responsibility of the NORSAR operation on 1 September 1971. Daily event summaries are edited and published regularly in NORSAR weekly Event Summaries. The publication of weekly summaries has been performed since September 1971.

Geophysical evaluations of LASA and NORSAR have been made since these arrays began regular operations (Barnard et al., 1972; Bungum and Bertenssen, 1972; Dean et al., 1971). These evaluations consider noise background, detectability, and threshold for each individual array.

This study is a geophysical comparison of the LASA and NORSAR short period arrays. Our purpose is to study the performances of the arrays to gain understanding of the basic characteristics of each and to investigate the possibility of improving each so that the worldwide coverage of seismic activities through the combined LASA-NORSAR system may also be improved. The study is grouped into four sections whose objectives are to:

1. Investigate similarities and differences in the nature of the arrays and their software parameters in an effort to find possibilities for improvements of performance.

2. Evaluate the basic geophysical character of each array and try to find clues to improvements in the DP and EP systems.

3. Investigate worldwide coverage of LASA, NORSAR, and the combined array system and discuss unconfirmed events in the coverage area.

4. Evaluate the possibility of improving the performance of each array with the aid of the event summaries of the other array.

A forty-day common data base, from 15 February to 25 March 1972, was selected for these comparisons. This period also covers the International Geophysical month from 15 February to 15 March 1972.

2. SYSTEM PARAMETERS

2.1 LASA-NORSAR Short-Period Array Parameters

Although LASA and NORSAR are large seismic arrays operating with similar software, many differences can be found in the field as well as in their Detection Processor (DP) and Event Processor (EP) systems. In Table I these array parameters have been compiled in order to make a comprehensive overview of the similarities and differences of LASA and NORSAR. These parameters are actual values that were in use during the data period. Many of these parameters are changeable; furthermore, some changes may cause significant differences in array performances.

Some similarities can be observed in the field parameters where the number of subarray and the array diameters are almost identical. However, the shapes of the arrays are not the same. LASA has five rings of subarrays (B-F) circumscribing a center subarray, AO, four subarrays in each ring, and the distance to the outer rings increases logarithmically. On the other hand, NORSAR is basically a hexagonal array with three rings (ABC) of subarrays where the number of subarrays per ring increases toward the outer ring; one in the center, seven in the B-ring, and 14 in the C-ring. The diameter of each subarray is approximately 7 km in both LASA and NORSAR. There are sixteen seismometers in each LASA subarray and six seismometers in a NORSAR subarray.

TABLE I

ARRAY PARAMETERS

		LASA	NORSAR
Location:	Latitude	46.7 N	60.83 N
	Longtitude	106.2 W	10.0 E
Total Seismometers		345	132
Subarrays		21	22
Array Diameter		E-ring 110 Km F-ring 200 Km	110 Km
Subarray:	number of beams/subarray	(SBS 104) 5	(SBS 123) 13 (SBS 124) 8
TOTAL SAB formed in SPS		85	342
Number of Array beams	SS (partition 1)	(LBS 133) 300	(NBS 401) 318
	GS (partition 2)	(LBS 140) 299	(NSBS 124) 64
Band Pass Filter		0.9 - 1.4 cps	1.2 - 3.2 cps
Sampling Rate	Subarray beams	10 sps	20 sps
	Array beams	5 sps	10 sps
	STA	1.69 sps	2 sps
	LTA	0.55 sps	0.67 sps
	Thresholding test	1.67 sps	2 sps
	Detection logic	1.67 sps	2 sps
Scale Factors, STA	SS	0.00287129 mμ/qu	0.001 mμ/qu
	GS	0.00271177 mμ/qu	0.005525 mμ/qu
	STA Averaging time	1.8 second	1.5 second
	LTA SS	0.000179456 mμ/qu	0.000125 mμ/qu
	LTA/STA	16	8
Threshold Logic	db ON, N	10db	10.5 db
	db OFF, N'	7db	7db
	Q/Q' TEST	3/3	1/1 SS, (1/0 GS)
Detection Logic (Stability)	Time, P	4	3
	Space, ΔU	2 beam rings	2 beam rings
Threshold Voting (NORSAR GS only)		-	3/8
Signal Limiting (Clipping threshold)		11 mμ	20 mμ
EP Threshold		14 db	12 db

Parameters in the two DP systems are mostly different, although their algorithms are the same. These differences characterize the basic nature of the arrays. Each subarray in NORSAR forms 13 subarray beams whereas LASA forms five beams in each subarry. Furthermore, NORSAR's subarray beams are fixed in location, i.e., all subarrays beam at the same fixed locations. This creates some fluctuation (variation) in beam losses. LASA's subarray beams are distributed in azimuths to average out beam losses evenly. In general, more subarray beams in DP surveillances would reduce beamforming losses. NORSAR's DP system forms more than twice the number of subarray beams formed by the LASA DP to reduce losses associated with NORSAR's higher frequency signals.

Signal detections are tested on successive intervals of 0.6 sec at LASA and 0.5 sec at NORSAR. Short Time Averages (STA) are computed by rectifying and integrating each filtered array beam over a period of 1.8 sec for LASA beams and 1.5 sec for NORSAR beams and they are renewed every 0.6 and 0.5 seconds, respectively. These STA's represent signal averages over the specified period of time. Similarly, Long Time Averages (LTA) are computed over 16 STA intervals at each site, and they are renewed every 1.8 sec at LASA and every 1.5 sec at NORSAR. LTA's are computed by exponentially weighting the previous LTA value and adding the current STA value. These LTA's represent noise averages of each beam at the time. The detection algorithms performs successive tests on STA's and STA/LTA ratios whenever STA's are computed.

There are two detection algorithms in each DP system. The first algorithm is the signal to noise ratio (S/N) threshold test which determines the size and duration of the signal. When the ratio of the STA/LTA exceeds the fixed threshold value of N db for the duration of Q times out of Q' consecutive tests, the signal arrival is declared "ON" on that beam. After the beam is turned ON, the end of signal arrival is declared when the S/N ratio of the beam becomes lower than the turn-off threshold of N' db; and the beam is turned "OFF". The turn-on threshold is set to 10 db for LASA DP and 10.5 db for NORSAR DP. The turn-off threshold is 7 db for both DP systems. The Q/Q' parameter is set to 3/3 for LASA DP and 1/1 for NORSAR DP. The LTA computation is stopped during the time the beam is turned on.

The second detection algorithm is the spatial coherency test. This algorithm determines the consistency of the seismic signal in both azimuth and velocity. When a seismic signal arrives at the array, high STA values may be observed in the neighboring beams. Thus, when STA's are computed at every interval of time, the algorithm seeks for the maximum STA beam and checks if the previous maximum was found within the distance of ΔU beams from the current maximum beam. When this condition is satisfied for P consecutive times, the signal arrival is declared on the beam with the highest STA value during these P consecutive tests. These parameters are set to P = 4, and ΔU = 2 for LASA DP, and P = 3 and ΔU = 2 for NORSAR DP.

Note that it is the spatial coherency algorithm that determines the signal arrival. When P maxima were found in beams within the specified ΔU area, the algorithm would then check if any of these beams satisfied Q/Q' test; and only if any beam is still "ON" when the P requirement is satisfied, is the detection declared. The major disadvantage of this algorithm is that when two seismic signals arrive at the array within the duration of P successive tests, it may fail to detect one or both of the signals.

2.2 Surveillance Area

Both LASA and NORSAR maintain two partitions of surveillance beam sets in their DP systems. In the first partition called the Selected Surveillance System (SS), array beams are aimed at various selected areas. There are 300 beams in LASA SS beam set, LBS133, and 318 beams in NORSAR SS beam set, NBS401. Most of these beams are P wave beams; 256 in LBS133 and 282 in NBS318. The rest of beams are core phase beams from various seismic regions. Each beam is also labeled with a processing priority code so that some of the detected signals may never be processed. In LASA, only those beams with priority code 1 will be processed through EP. These are P wave beams within the teleseismic range of 30° to 90°. In NORSAR, some core phase beams are processed along with P wave beams. In forming these DP beams, all 22 subarrays contribute to NORSAR SS beams. In LASA, 17 subarrays from the A to the E ring are used.

The second partition is called the General Surveillance (GS) system. In the LASA/SAAC system, GS beams use only the nine subarrays in the A, B, and C rings. Since the array diameter is smaller, each beam can cover broader areas than SS beams. The GA beams are set to cover teleseismic areas uniformly; therefore the area of coverage of LASA GS beams is approximately from $\Delta = 20°$ to $\Delta = 180°$. Local and regional events of less than 20° of distance from the array are not covered in both LASA and NORSAR.

NORSAR used a different detection algorithm in the second partition (IBM, 1968). Eight subarrays are chosen to form eight selected beams; one infinite-velocity beam and seven regional beams (within a distance of 30°). Rectify-Integrate-Threshold algorithms are applied to these subarray beams, and detections are declared if three out of eight subarray beams exceeded the detection threshold. Due to the difference in this algorithm, consideration of this partition is excluded from the present study.

The main basis of this comparison is the P wave beams of LASA beam set 133 and of NORSAR beam set 401 in the first partition. In Table II we have grouped the P wave beams of LASA and NORSAR into 50 seismic regions. Core phase beams are not listed in this table.

TABLE II

LASA-NORSAR P WAVE BEAM DISTRIBUTIONS IN SEISMIC REGIONS

		Number of Beams in Region	
		LASA	NORSAR
1	ALASKA - ALEUTIAN ARC	23	24
2	EASTERN ALASKA TO VANCOUVER ISLAND	0	2
3	CALIFORNIA - NEVADA REGION	0	14
4	BAJA CALIFORNIA AND GULF OF CALIFORNIA	0	3
5	MEXICO - GUATEMALA AREA	6	8
6	CENTRAL AMERICA	6	9
7	CARIBBEAN LOOP	10	8
8	ANDREAN SOUTH AMERICA	20	5
9	EXTREME SOUTH AMERICA	1	0
10	SOUTHERN ANTILLES	0	0
11	NEW ZEALAND REGION	0	0
12	KERMADEC - TONGA - SAMDA AREA	4	0
13	FIJI ISLANDS AREA	1	0
14	NEW HEBRIDGES ISLANDS	1	0
15	BISMARCK AND SOLOMON ISLANDS	0	0
16	NEW GUINEA	0	0
17	CAROLINE ISLANDS TO GUAM	0	0
18	GUAM TO JAPAN	1	6
19	JAPAN - KURILES - KAMCHATKA	10	18
20	SOUTHWESTERN JAPAN AND RYUKYU ISLANDS	2	5
21	TAIWAN	1	2
22	PHILIPPINES	0	4
23	BORNEO - CELEBES	0	0
24	SUNDA ARC	0	1
25	BURMA AND SOUTHEAST ASIA	0	3
26	INDIA - TIBET - SZECHWAN - YUNAN	0	18
27	SOUTHERN SINKIANG TO KANSU	1	11
28	ALMA-ATA TO LAKE BAIKAL	14	13
29	WESTERN ASIA	5	15
30	MIDDLE EAST -CRIMEA -BALKANS	6	12
31	WESTERN MEDITERRANEAN AREA	4	1
32	ATLANTIC OCEAN	25	34
33	INDIAN OCEAN	0	15
34	EASTERN NORTH AMERICA	1	6
35	EASTERN SOUTH AMERICA	0	0
36	NORTHWESTERN EUROPE	4	0
37	AFRICA	1	9
38	AUSTRALIA	0	0
39	PACIFIC BASIN	29	1
40	ARCTIC ZONE	22	5
41	EASTERN ASIA	14	12
42	NORTHEASTERN ASIA, NORTHERN ALASKA TO GREENLAND	13	1
43	SOUTHEASTERN AND ANTARCTIC PACIFIC	7	0
44	GALAPAGOS AREA	11	1
45	MACQUARIE LOOP	0	0
46	ANDEAN ISLANDS TO SUMATRA	0	6
47	BALUCHISTAN	0	2
48	HINDU KUSH AND PAMIR	2	7
49	NORTHERN ASIA	11	1
50	ANTARCTICA	0	0

The geographic distribution of LBS133 and NBS401 P wave beams is shown in Figures 1 and 2 respectively.

2.3 System Reliability

Table III is the tally of system down time and problems encountered during the test period. This indicates that NORSAR's down time was approximately 2% of the total time, and LASA/SAAC was nearly 5% during this period. No attempts were made to retrieve detections during down time. System logs and the quarterly published at SAAC show that the SAAC system down time ranges from 2% to 5% of the available time.

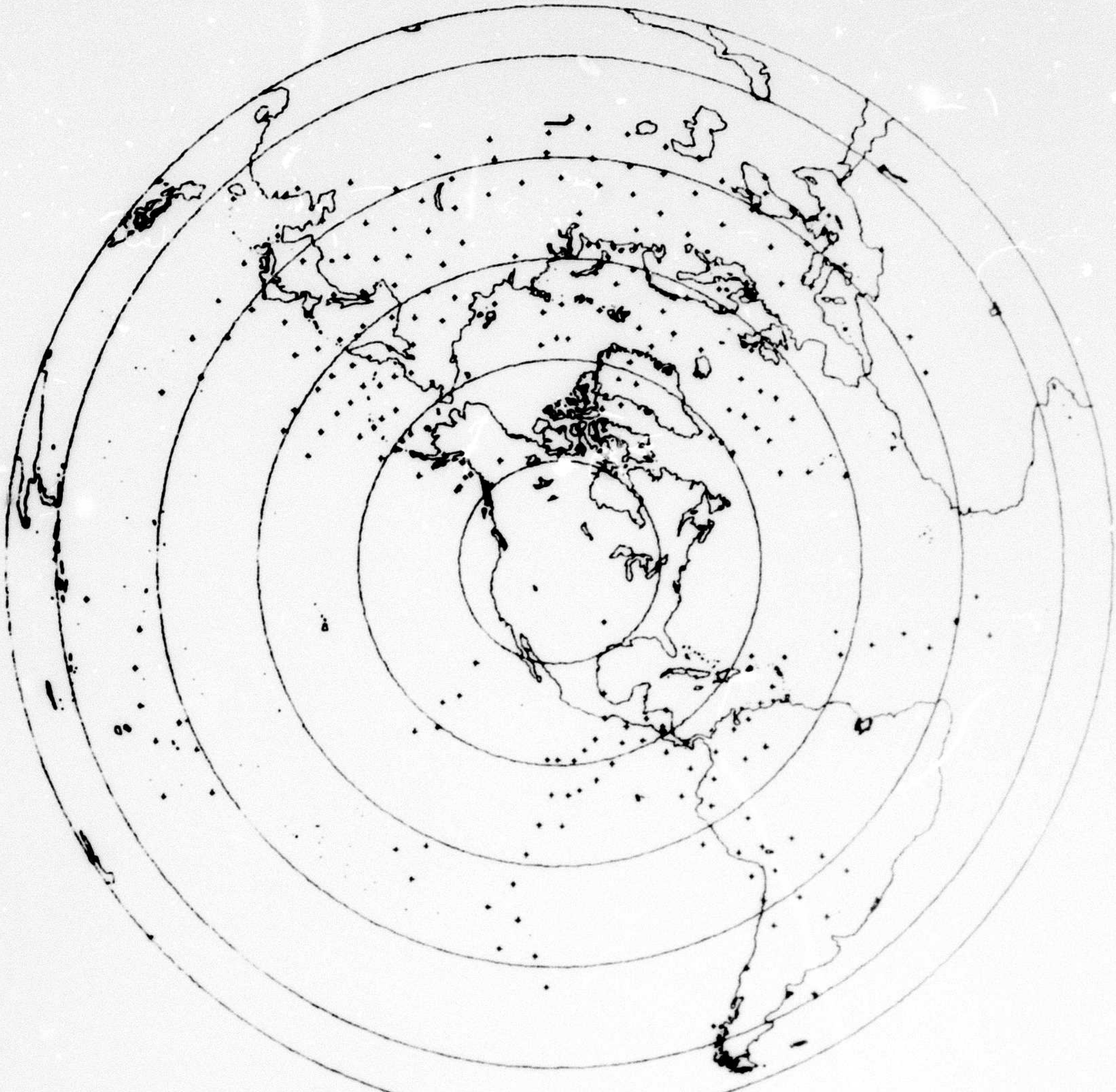


Figure 1. Distribution of LASA SS beams, LBS133.

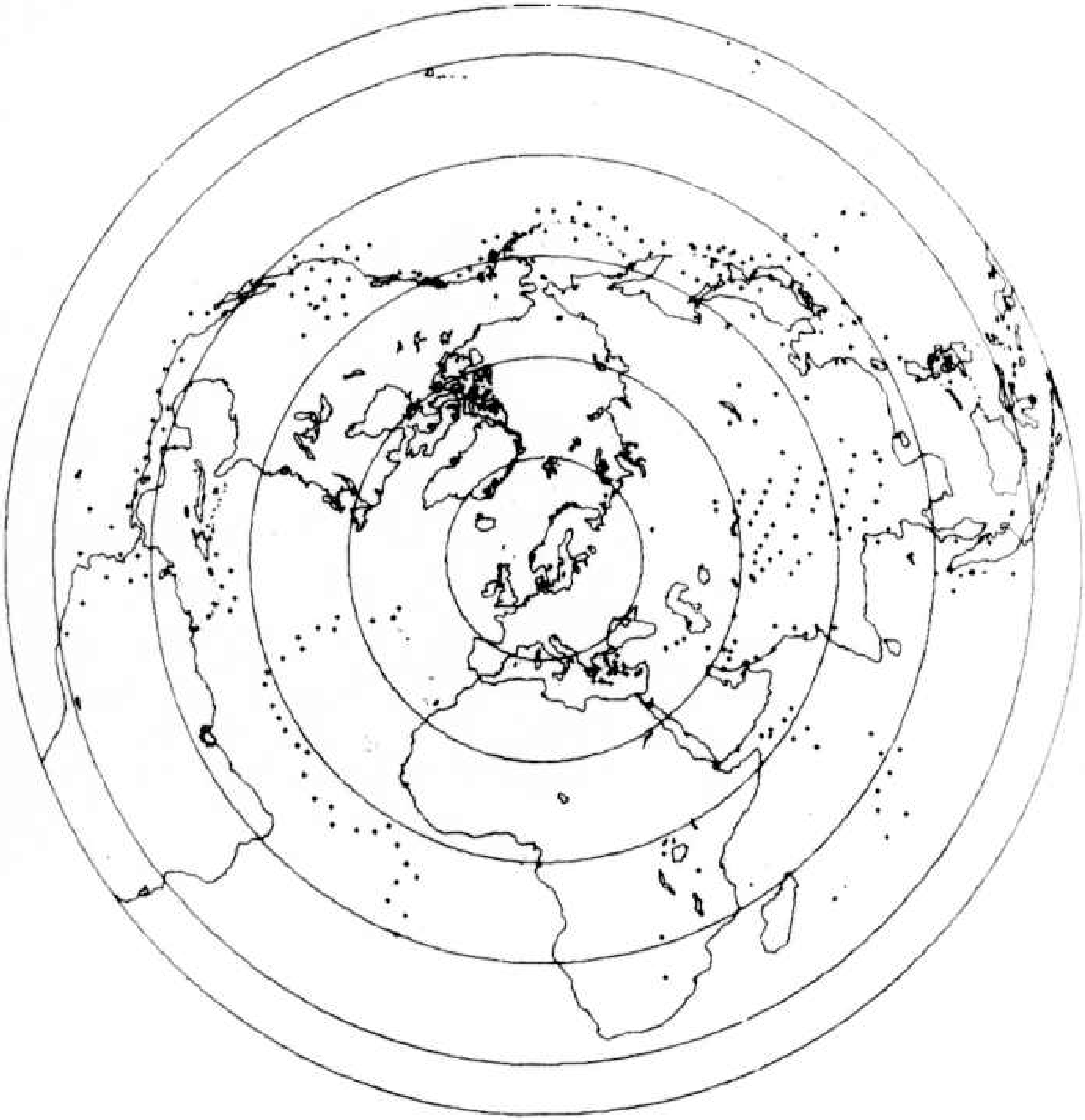


Figure 2. Distribution of NORSAR SS beams, NBS318.

TABLE III

LASA & NORSAR SYSTEM DOWN TIME

Problems		Down Time (Minutes)	%
Total Available Time		57600	100
NORSAR Down (DP & SPS)		1345	2.335
Data lost in Trans-Atlantic Line		31	0.054
Data lost in LDC and Cable		513	0.891
SAAC Down,	SPS	403	0.699
	DP	1938	3.365
	Power Failure	55	0.095

3. ARRAY CHARACTERISTICS

3.1 Noise Average and Hourly Detections

The hourly averages of noise level, detections, and events being processed by EP for LASA and NORSAR for the period 15 February to 25 March 1972, are shown in Figure 3.

The noise average presented here is the average of LTA (long-time average) values measured when signals were detected. In other words, this is the average noise level on filtered beams. These LTA values were actually used in the signal-to-noise threshold tests; therefore they are directly related to the detection threshold of each array.

Two features can be observed from Figure 3: diurnal variation of noise averages, and several high peaks deviating from the diurnal variation, with more peaks observed in LASA noise averages than in NORSAR. Two reasons may explain such sudden increase in hourly noise averages. The first is that the noise average reflects the coda of a large event. In this case the high noise level can be correlated in LASA and NORSAR records. Such a correlation occurs at 0900 GMT in Figure 3 (A) and (D). The rest of the high hourly noise averages at LASA are not correlated with NORSAR noise averages.

The second explanation is purely a computational problem of signal contamination due to the length of

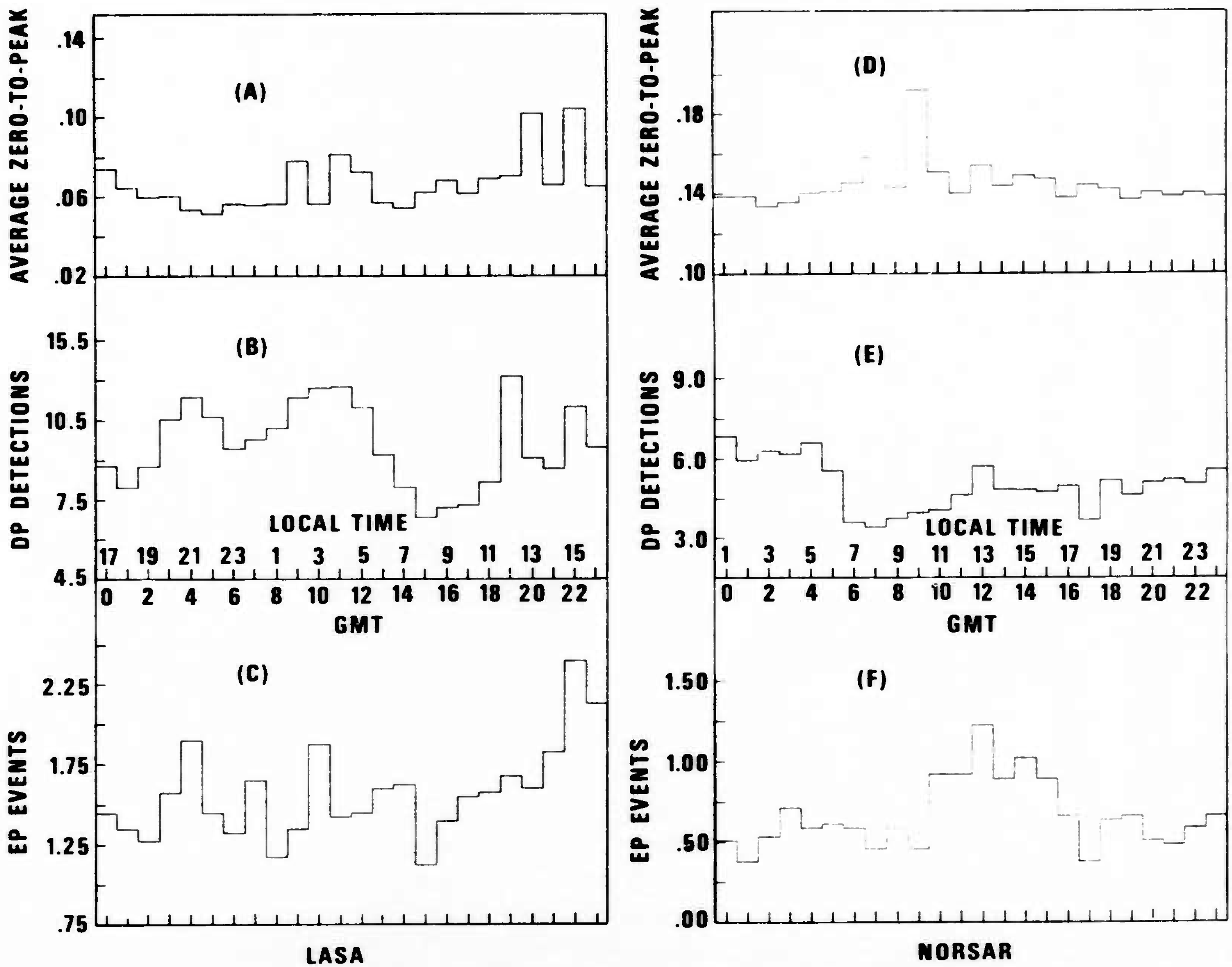


Figure 3. Hourly averages of LASA and NORSAR noise, number of detections and number of events being processed. LASA data prefiltered to the band 0.9-1.4 Hz, and NORSAR to 1.2-3.2 Hz.

the time required to satisfy the Q/Q' threshold test. Study of the S/N thresholding algorithm (microcode) shows that the threshold test is performed after the STA is computed. If the Q/Q' test is not satisfied and if this is one of the LTA update times, the algorithm will proceed to update the LTA using the current STA value. The LTA is updated once every three STA computation times. After the arrival of signal is declared the LTA updates will be stopped until the end of arrival is declared. It can be seen therefore that when Q/Q' is 1/1, as in the NORSAR DP, there is no chance of signal contamination in the LTA measurements. If Q/Q' is 2/2, there will be one chance in three that one third of the current STA window may contain part of the arriving signal. If Q/Q' is 3/3, as in the LASA DP system, there will be one chance in three that one third of the data in the STA window will contain part of the arriving signal, and one chance in three that two thirds of the data in the STA window will contain the first part of the arriving signal. Thus, the arrival of a few large signals can explain the observed peaks in LASA hourly noise averages. Further evidence of this finding will be examined in the LASA DP recurrence curves. It is not clear at present what quantitative effect this contamination of the LTA has on the detection threshold of the array.

Excluding these unusual high LTA values from LASA and NORSAR, the diurnal variation of noise level for LASA may be observed to be between 0.05 to 0.07 mμ, averaging about 0.6 mμ. Similarly, the diurnal variations for NORSAR averages about 0.14 mμ. This indicates that, regardless of the basic noise background in the array the contribution of cultural noise to the array detection system is constant at approximately 0.02 mμ.

3.2 Daily Averages

Daily averages of noise, detections, and events are shown in Figures 4, 5, and 6, respectively. Zero values in these histograms indicate the systems were down most of the day.

The daily averages of LASA noise levels are usually stable in the 0.06 mμ area. The noise variation at NORSAR ranges from 0.10 to 0.18 mμ, showing somewhat cyclic changes. The daily DP detections at LASA in general range between 200 and 300, and those at NORSAR between 90 and 150.

The daily processed events indicate more variations, ranging from 25 to 55 per day for LASA and 10 to 25 for NORSAR. As a general conclusion, the ratio of noise level/detections/events per day is 0.06 mμ/250/30 at LASA, and 0.14 mμ/120/15 at NORSAR. At both LASA and NORSAR, the number of published events is approximately 12% of daily DP detections.

3.3 Recurrence Curves

The recurrence curves for LASA and NORSAR detections are shown in Figure 7. At both LASA and NORSAR,

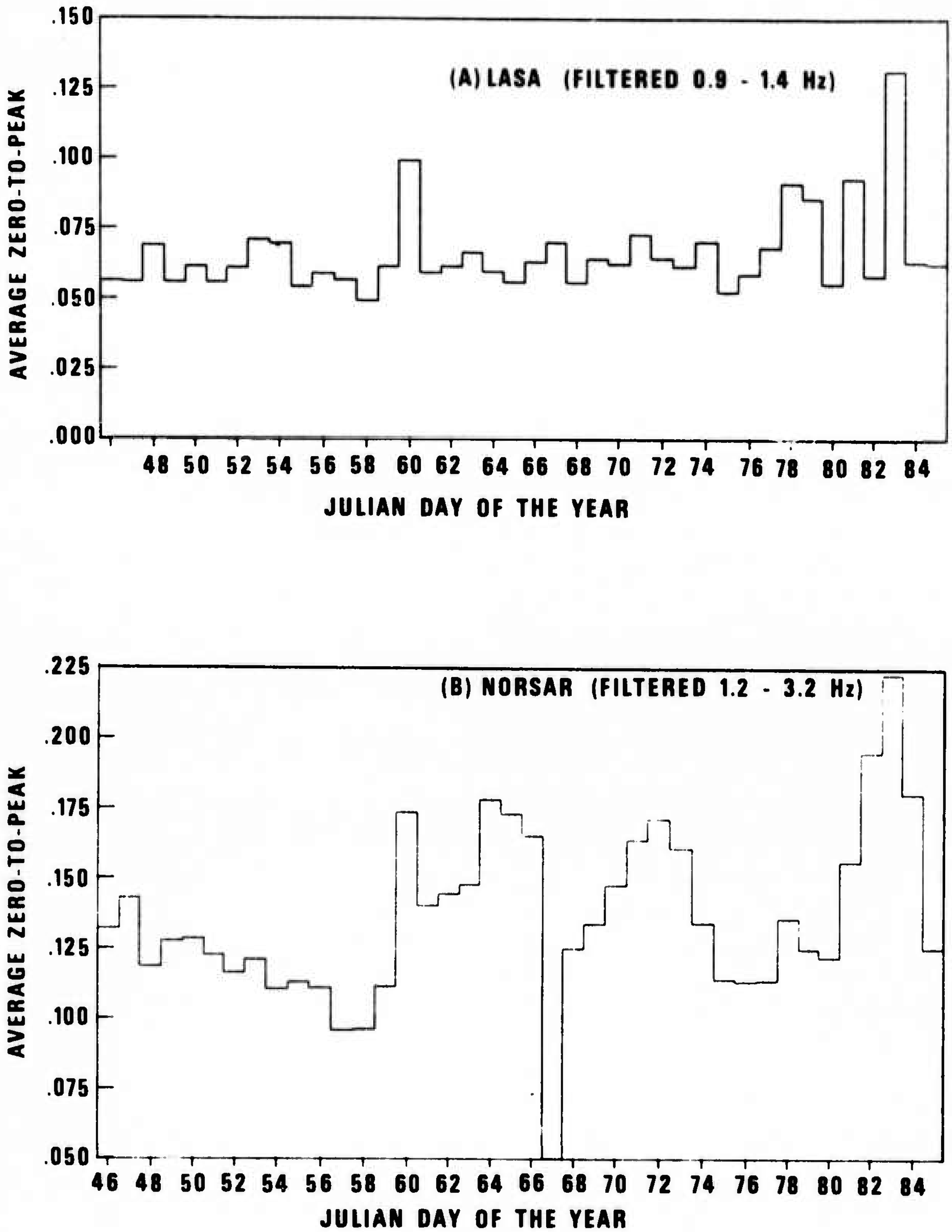
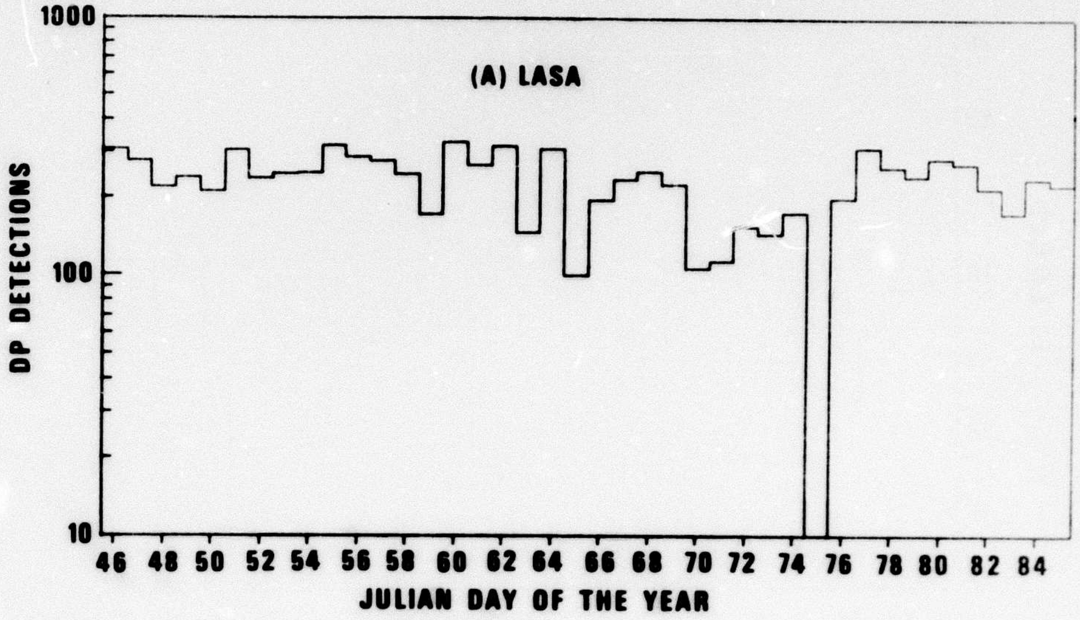


Figure 4. Comparison of LASA and NORSAR daily noise averages on the beam.



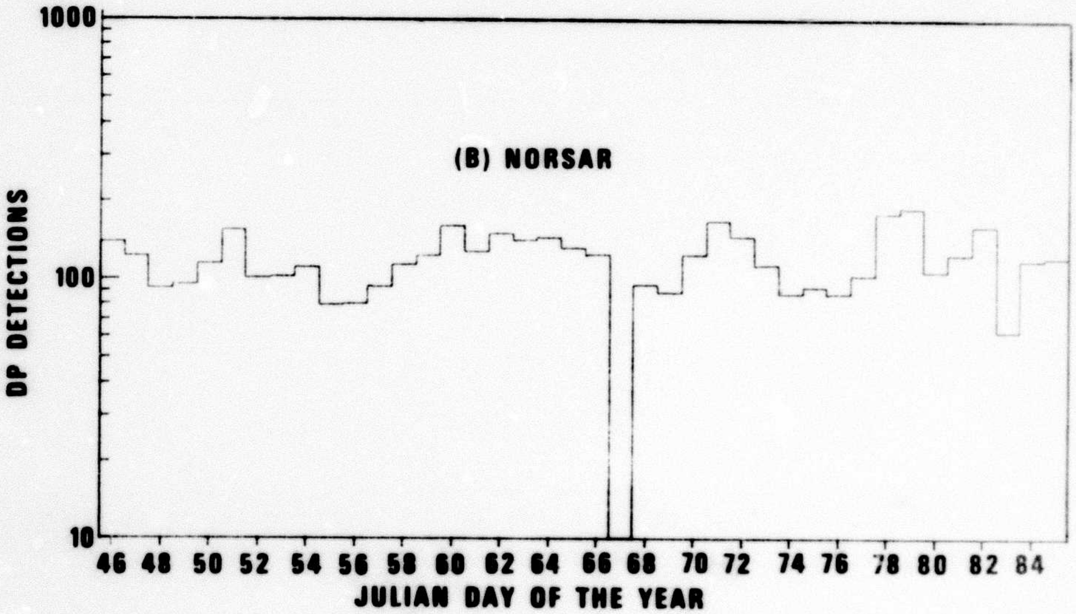
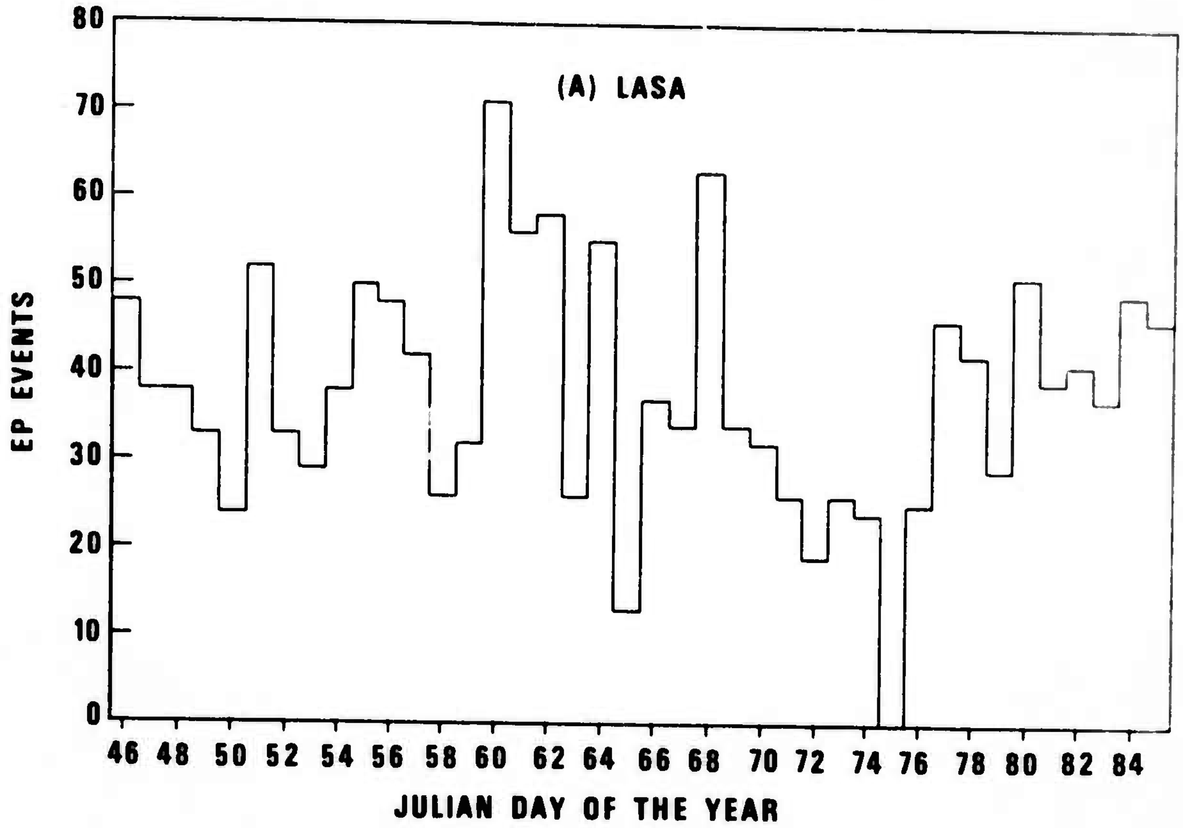


Figure 5. Comparison of LASA and NORSAR daily averages of number of detections.



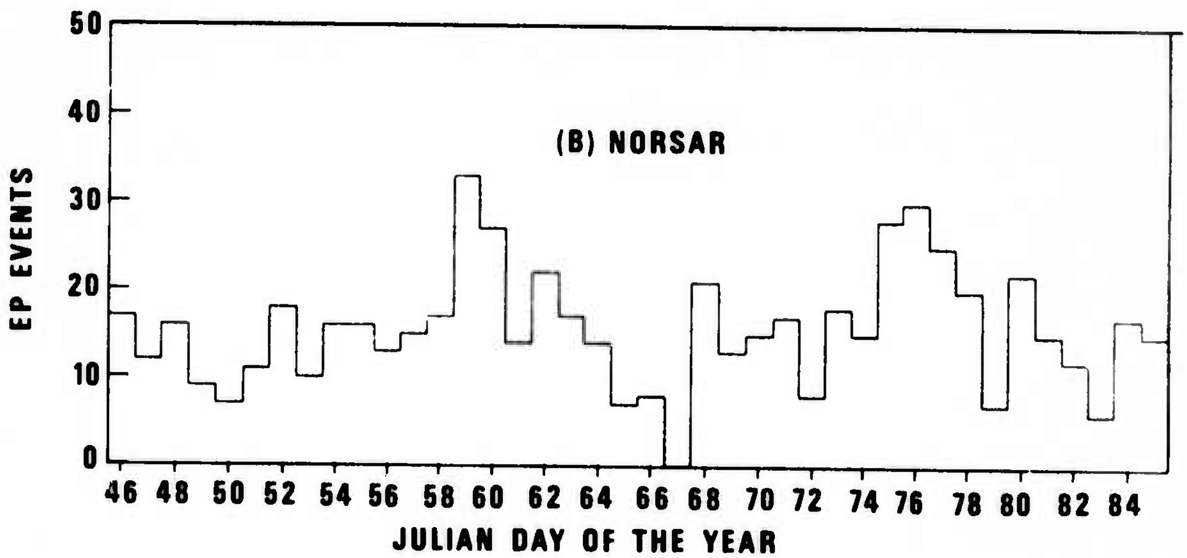


Figure 6. Comparison of LASA and NORSAR daily averages of EP processed events.

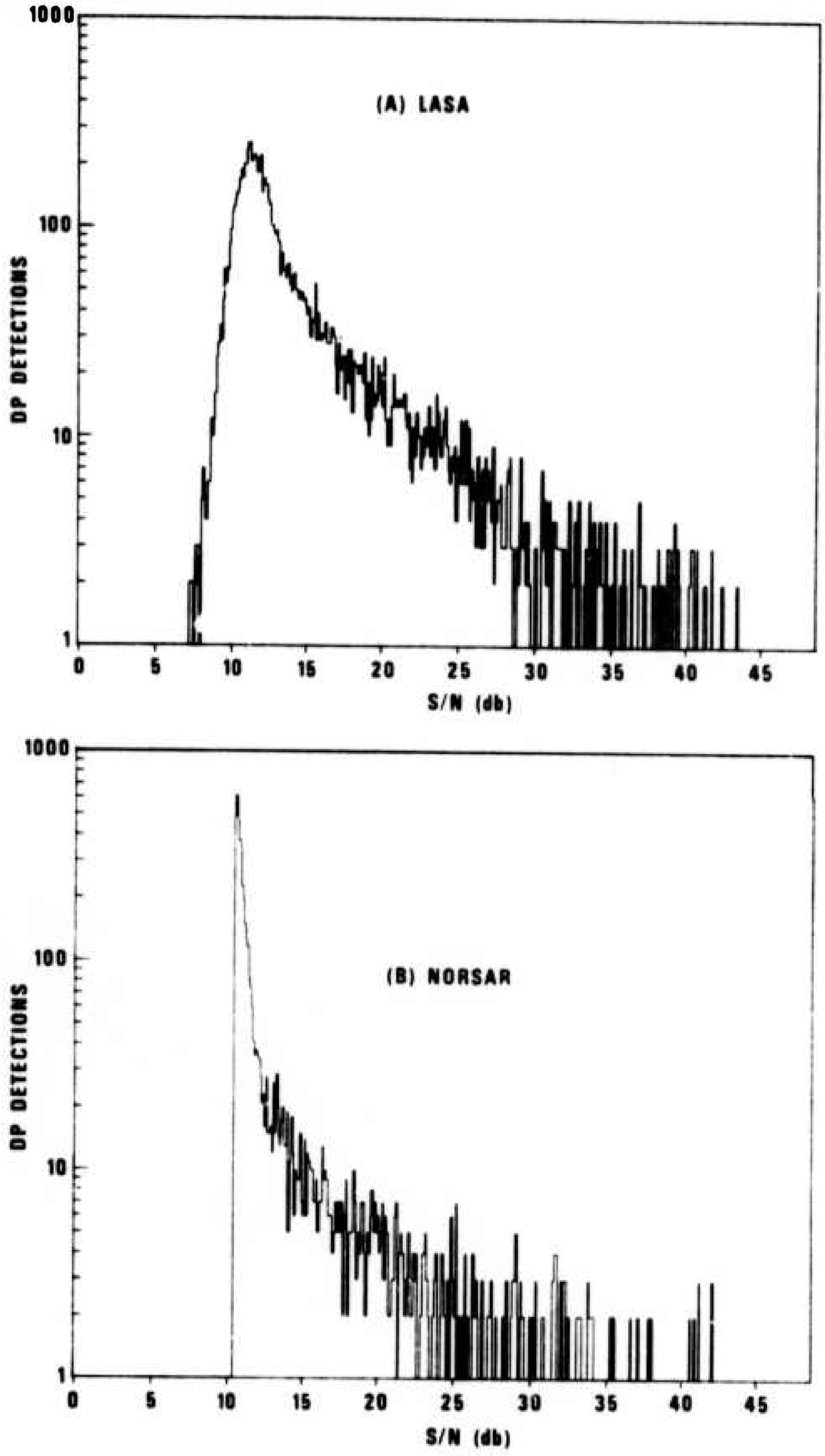


Figure 7. LASA and NORSAR discrete DP recurrence curves.

the number of detections shows sudden increases at the low db end of their curves, indicating deviations from the recurrence curves of real seismic events. Two reasons may be considered to explain these deviations. The first is the detection of secondary phases from large events, so that all secondary detections contribute to the lower end of the curve. Such contributions of secondary phases should be common and acting equally at both arrays. The second is the detection of false alarms of non-seismic origin.

The fact that a 3/3 parameter in the detection algorithm will contaminate the LTA measuremnt is shown in the 10 db cutoff in the recurrence curves. NORSAR detections show a distinct cutoff at 10.5 db, as specified by the threshold test. On the contrary, the LASA detection curve shows a decrease from 11 db and spills over to approximately 7.5 db. This verifies the fact that when Q/Q' consecutive tests are satisfied using 3/3, some LTA values may include part of the signal. As a consequence, many detections above EP threshold (14 db) may also be omitted because the high LTA value may lower the computed signal to noise ratios below the EP threshold. The problem encountered in the selection of the Q/Q' parameter is now clear: 1/1 may increase the chance of false alarm detections; 3/3 may omit some good detections. Since the threshold algorithm is microcoded and changes in microcodes are costly, one alternate choice of the Q/Q' parameter is 2/2 for both LASA and NORSAR.

The best choice of DP parameters for both LASA and NORSAR might therefore be Q/Q' = 2/2. For the spatial coherency parameter P, P = 4 should be adequate for teleseismic events at LASA (Dean et al., 1971). However, it was suggested that P = 3 may be suitable for regional and impulsive events (K. J. Deahl, personal communication, April 1971). Clearly if the spatial coherency is a function of epicentral distance but the choice of a P parameter based on distance is not available in the system, P = 4 is probably the optimum choice.

3.4 Recurrence Curves, Signal Losses and Array Thresholds

Since STA's are calibrated to represent zero-to-peak ground motion (referenced to the peak value of a 1 Hz sine wave), recurrence curves in terms of amplitude may be constructed by plotting the number of detections against log (STA). Like actual recurrence curves, they can be used to estimate the m_b thresholds of LASA and NORSAR. Figure 8 shows cumulative recurrence curves constructed in this manner. The upper end of these curves are limited by clipping the thresholds of individual seismometers at 11 mμ for LASA and 20 mμ for NORSAR.

The 90% cumulative threshold amplitudes for EP events were estimated from these curves as 0.35 mμ for LASA and 0.5 for NORSAR. Since these are signal amplitudes (STA) detected by the DP beams of each array, they must be corrected for the losses associated with each beam.

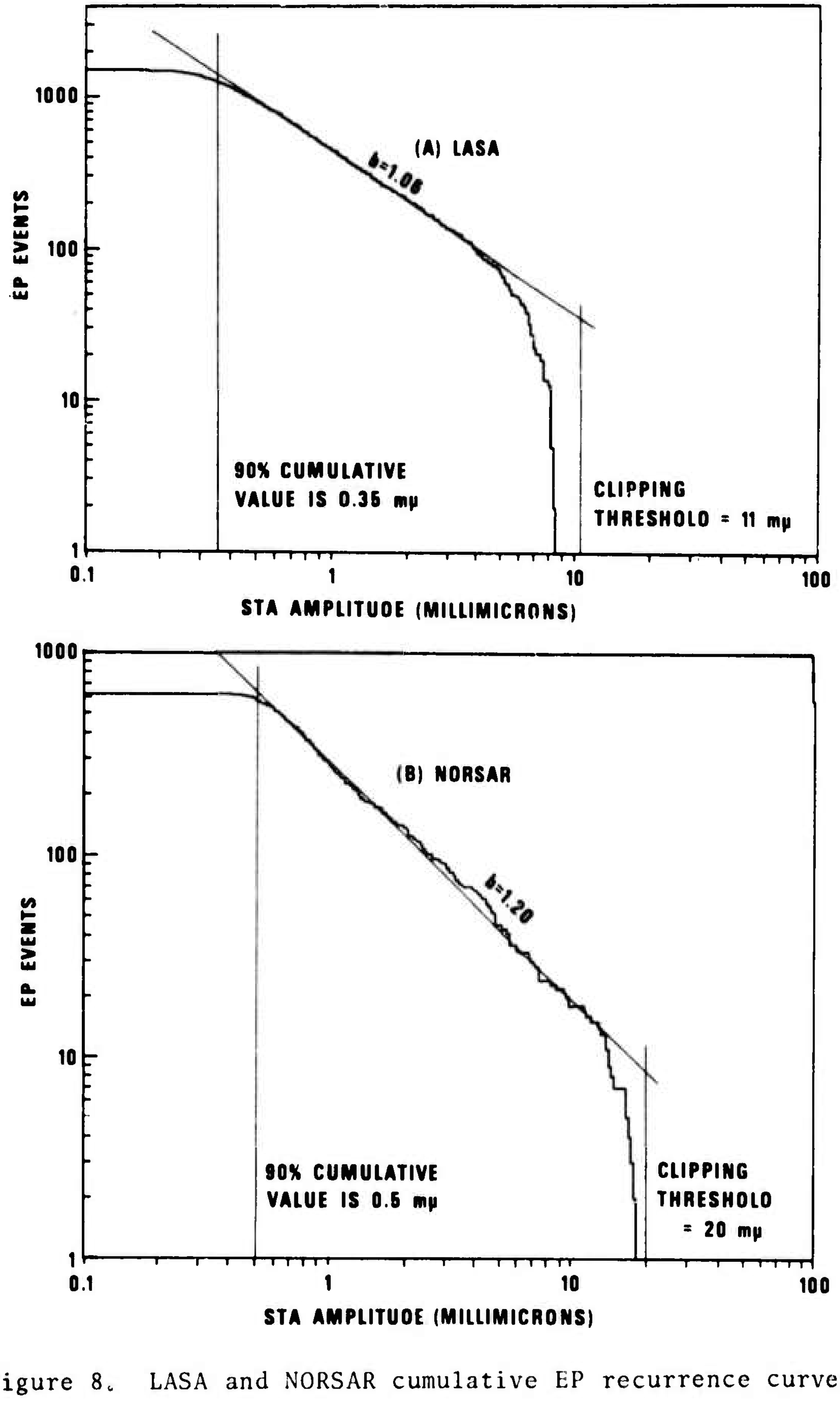


Figure 8. LASA and NORSAR cumulative EP recurrence curves.

4. COMPARISON OF EVENTS

4.1 Purpose of Event Comparison

Comparisons of LASA and NORSAR Event Summaries are made for two purposes. The first is to evaluate the coverage of worldwide seismic events by LASA and NORSAR, i.e., the percentage of the world areas covered by one array only and the area covered by both. The second is to evaluate the degree of mutual assistance in confirming events.

In the study of the area of coverage one may use the NOAA PDE (Preliminary Determination of Epicenters) list for worldwide seismic events. A certain amount of bias is made unavoidable by using the NOAA PDE list, since the NOAA threshold is higher than those of LASA and NORSAR. The comparison will not of course confirm any event not reported in the PDE list. The total number of events reported during the period from 15 February to 25 March 1973 are: LASA/SAAC 920; NORSAR 542, and PDE list 483. Nearly half of the 437 reported by LASA/SAAC events are not confirmed by the NOAA PDE list, whereas only 59 NORSAR events are not confirmed by the PDE list. Furthermore, one must be aware in this comparison that the NOAA m_b threshold is not uniform throughout the world because regional seismic networks are contributing to the list. For event summaries of each array, LASA reports only events of P wave beam detections of approximately 30° - 90° range, whereas NORSAR event summary includes some events detected in core phase beams.

For the study of the mutual assistance of LASA and NORSAR, one can directly compare Event Summaries and Detection reports for mutual confirmation and for unconfirmed events. Some degree of uncertainity is inherent in this comparison, for it must trust the Event Summary of the array as to whether the reported event is real or not. One may compensate for this by comparing unconfirmed events with NOAA PDE lists or EP re-runs. Despite these uncertainities we feel that generally adequate conclusions may be drawn from such a study.

4.2 Comparison with the NOAA PDE List

A total of 483 events were reported by NOAA on the PDE list during the period. These events were compared with the LASA and NORSAR event summaries, as shown in Table IV. The table is divided into four groups which show in numerical order the total number of events reported by either array, by both arrays, by only one of the arrays, and the total number of events which were not reported by either LASA or NORSAR.

Part I of Table IV shows that of the 483 events in the set, 350 (73%) were confirmed either by LASA or NORSAR. A total of 271 or 56% of the 483 were reported by LASA and 256 or 53% by NORSAR.

Parts 2 and 3 of Table IV show a breakdown of the 350 events reported by either array, a total of 177 of 350 events were confirmed by both arrays; this is about 37% of the 483 events on the PDE list. The remaining

TABLE IV

COMPARISON OF LASA & NORSAR EVENT SUMMARIES WITH NOAA PDE LIST

1. WORLDWIDE COVERAGE

TOTAL NOAA EVENTS	483	%
1. Total confirmed by either LASA or NORSAR	350	72.5%
(a) Total LASA confirmed	271	56.1%
(b) Total NORSAR confirmed	256	53.0%
2. Both LASA & NORSAR confirmed	177	36.7%
3. Only one array confirmed	173	35.8%
(a) LASA	94	19.5%
(b) NORSAR	79	16.3%
4. Unconfirmed by either LASA or NORSAR	133	27.5%
(a) Both LASA & NORSAR out of range	54	11.2%
(b) LASA in range, missed, but NORSAR out of range	12	2.5%
(c) NORSAR in range, missed, but LASA out of range	49	10.1%
(d) Both in range, missed	18	3.7%

173 (~36% of the total PDE set) events were reported by one array but not the other; of these LASA reported 94 events and NORSAR reported 79.

We said above that 350 of the 483 events on the PDE list were confirmed by either LASA or NORSAR. The remaining 133 events were not reported by either array. Of these events 54 were out of the P wave range of both arrays; 12 were in LASA's range only; 49 were in NORSAR's range only; and 18 were in the P wave range of both arrays.

Table V shows the study of unconfirmed events in this comparison. Of 483 PDE events, 161 events, or 33%, are out of the LASA surveillance region. Similarly, 103 events or 21% are out of the NORSAR surveillance region. The 12% difference is due partly to seismicity and partly to the fact that LASA EP is set to process only P wave detections of 30° to 90° range, where NORSAR EP is set to process some additional core phase detections.

Among these PDE listed events within the range, LASA confirmed 84.2% of events. Similarly, NORSAR confirmed 67.4%.

Missed events due to system down time are 9.6% for LASA and 4.0% for NORSAR. The rest of the missed events, 6.2% for LASA and 28.2% for NORSAR, are grouped in three categories: (a) DP failed to detect the signal arrival (b) DP detected the arrival, but failed the EP processing threshold, and (c) EP processed but

TABLE V

COMPARISON OF LASA & NORSAR EVENT SUMMARIES

WITH NOAA

2. STUDY OF UNCONFIRMED EVENTS

	LASA		NORSAR	
	Number	%	Number	%
Total PDE events	483		483	
Events out of surveillance of the array, or no beam in the area	161		103	
Total events in surveillance range	322	(100%)	380	(100%)
Total confirmed events	271	84.2	256	67.4
Total Unconfirmed events	51	15.8	124	32.6
1. System down	31	9.6	15	4.0
2. Total missed events	20	6.2	109	28.6
(a) DP failed to detect	9	2.8	85	22.4
(b) DP detected but failed EP threshold	6	1.8	20	5.3
(c) EP processed but failed to confirm	5	1.6	4	0.9

failed to confirm the event. This study showed that a significantly high number of 85 PDE listed events (22.4%) were not confirmed by NORSAR because the DP system failed to detect signal arrivals. Occurrences of these missed events show concentrations in 10 seismic regions. These ten frequently missed regions are shown in shaded areas in Figure 9. The world is plotted in inverse velocity (U) space from NORSAR in order to show that these regions are within the P wave range U = 0.08 - 0.04 sec/km. Also, squares in the U-space map indicate the aiming point of subarray beams. Most of these missed event regions are very close to subarray aiming points, so that we are sure that subarray beam loss is not the cause of these missed detections. The remaining plausible explanations are: (a) travel-time residuals are not adequately calibrated for these regions; and (b) amplitude anomalies may cause poor signals from these regions.

4.3 Comparison of LASA and NORSAR Event Summaries

In the previous section we discussed those events reported by LASA and NORSAR which appeared on the PDE list. The arrays, however, report many additional events. In this section of the report we are concerned in general with the gross event summaries from the arrays, and in particular with events within the range of both arrays which were reported by both.

The comparison arbitrarily accepts published events as real. When both arrays report the event, chances

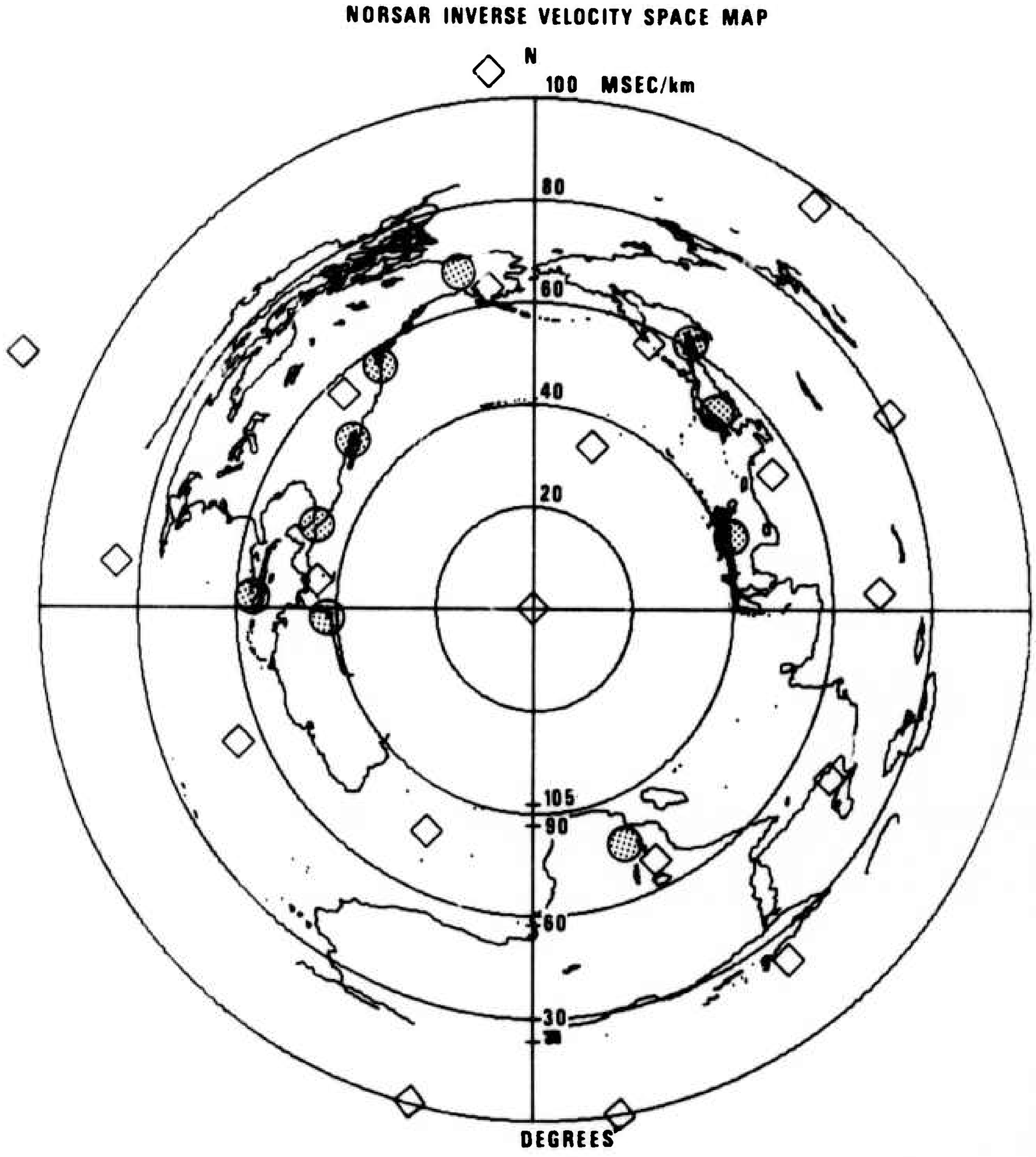


Figure 9. NORSAR inverse velocity map showing locations of NORSAR missed events in stippled circles. Squares in the map are locations of NORSAR subarray beams.

are good that it is real whether PDE list reported it or not. In the present case, 272 events were common to both LASA and NORSAR event summaries, and to the area mutually covered by the arrays. The results of this comparison are summarized in Table VI. Among 542 NORSAR events compared to LASA events, we excluded 153 events as being either out of the surveillance area or as being within the LASA range but having no beam directed to the epicenters. The remainder is 389 events, 71.8% of the NORSAR events, which can be compared to LASA. Similarly, out of 920 LASA events, 204 events were excluded as out of the NORSAR surveillance area or as having no NORSAR beam in the area. The remainder of 716 events or 77.8% are the possible LASA events to be confirmed by NORSAR. Percentage of coverage area is higher for NORSAR because some core phase beams are being processed by NORSAR EP.

From 389 NORSAR-reported events, LASA EP confirmed 272 events, or 70%. Among the unconfirmed events, 43 events (11.1%) are due to system failure, 28 events (7.2%) failed the DP detection, and 46 events (11.8%) were detected but failed EP threshold. These 74 LASA missed events were input to EP re-runs, and analysts agreed to confirm 19 events, 5 that failed EP, and 14 that failed the EP threshold. These are the type of events LASA would be able to retrieve if the daily operation made full use of the NORSAR Event Summaries.

Similarly, among 716 LASA published events, NORSAR Event Summaries confirmed the same 272 events (38.0%).

TABLE VI

COMPARISON OF LASA & NORSAR EVENT SUMMARIES

	LASA	%	NORSAR	%
Total Events in mutual coverage area	389*	100%	716**	100%
Total confirmed events in mutual area	272	70.0	272	38.0
Total unconfirmed events in mutual area	117	30.0	444	62.0
(1) System down	43	11.0	35	4.9
(2) Total missed events	74	19.0	409	57.1
(a) DP failed to detect	28 (5 confirmed by EP rerun)	7.2	320 (27 confirmed by NOAA)	44.7
(b) DP detected but failed EP threshold or EP failed	46	11.8	89	12.4

* Total number of Events on the NORSAR summaries which are within LASA's range.

** Total number of events on the LASA summaries which are within NORSAR's range.

Of the 444 unconfirmed events, 35 events (4.9%) are due to system down time, 320 events (44.7%) failed DP detections, and 89 events (12.4%) were detected but failed EP processing threshold. Thus, the majority of unconfirmed events are due to DP failure to detect the signal. Since the average LTA of NORSAR is approximately 7 db above that of LASA's, NORSAR can not detect most of these signals unless the S/N threshold is set to 7 db below LASA's EP processing threshold (14 db). Another possible reason for high DP misses at NORSAR is signal losses caused by inaccurate corrections for travel time anomalies. Signal losses are also associated with the higher frequency band pass filter applied to NORSAR beams. Comparing these unconfirmed LASA events to the NOAA PDE list, 27 events out of 320 missed events at NORSAR were confirmed by the PDE list.

If LASA and NORSAR can compare their DP detections and EP events on a daily basis, some events may be salvaged by re-processing. For data recorded from 15 February to 25 March, LASA's re-processing confirmed an additional 14 events from unconfirmed events, indicating the average of one event in every three days may be added to the LASA bulletin. For NORSAR, if all events detected on NORSAR DP but not on NORSAR EP could be recovered then perhaps 2 events per day may be added by comparing with LASA detections and Event Summaries.

4.4 Magnitude Comparison

LASA and NORSAR magnitudes are compared in two groups: (1) Japan and Off the East Coast of Japan regions, and (2) Kurile Islands Region. These comparisons are shown in Figures 10 and 11. No appreciable bias was observed in these comparisons.

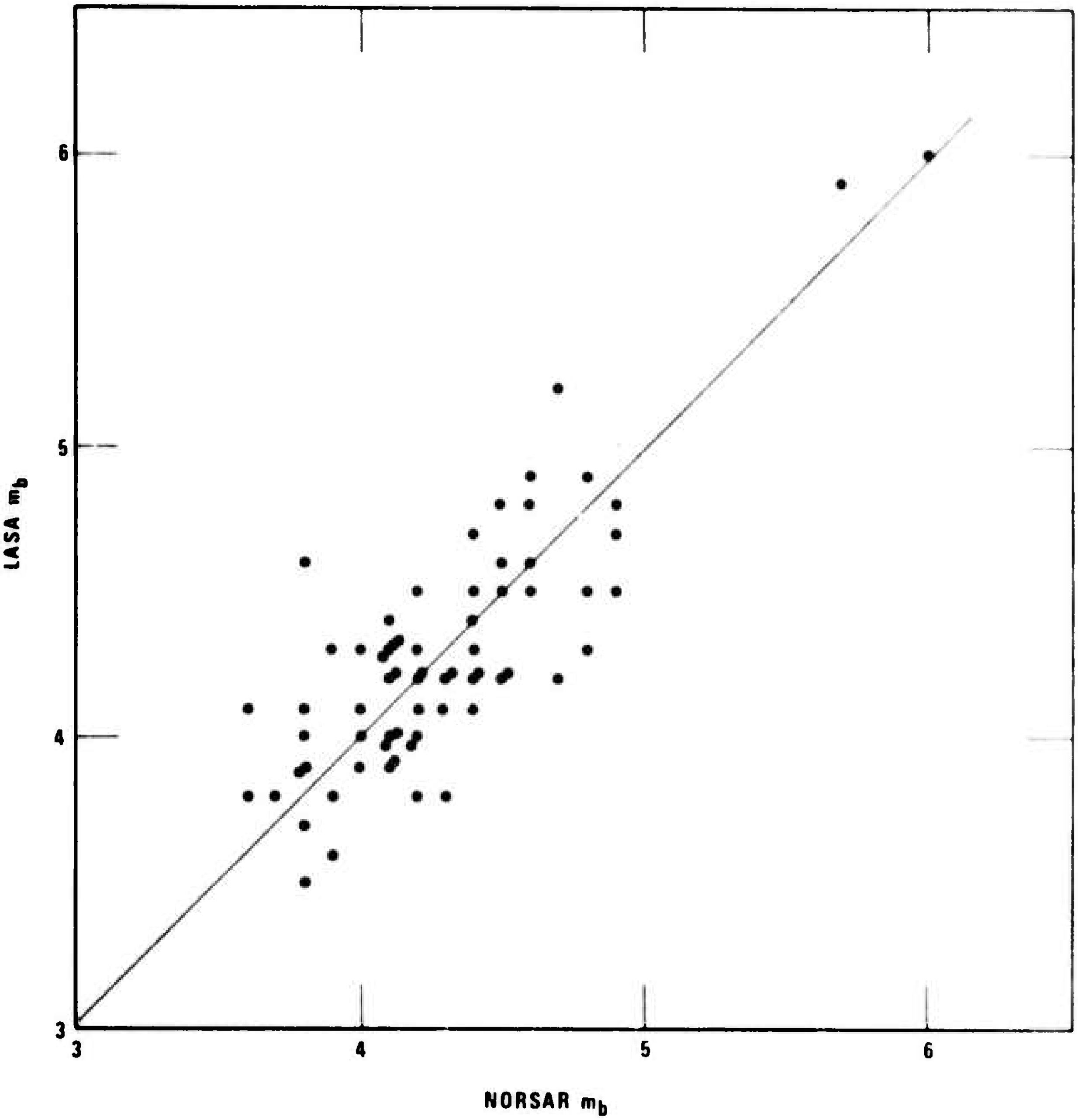


Figure 10. LASA-NORSAR m_b comparison - Japan region.

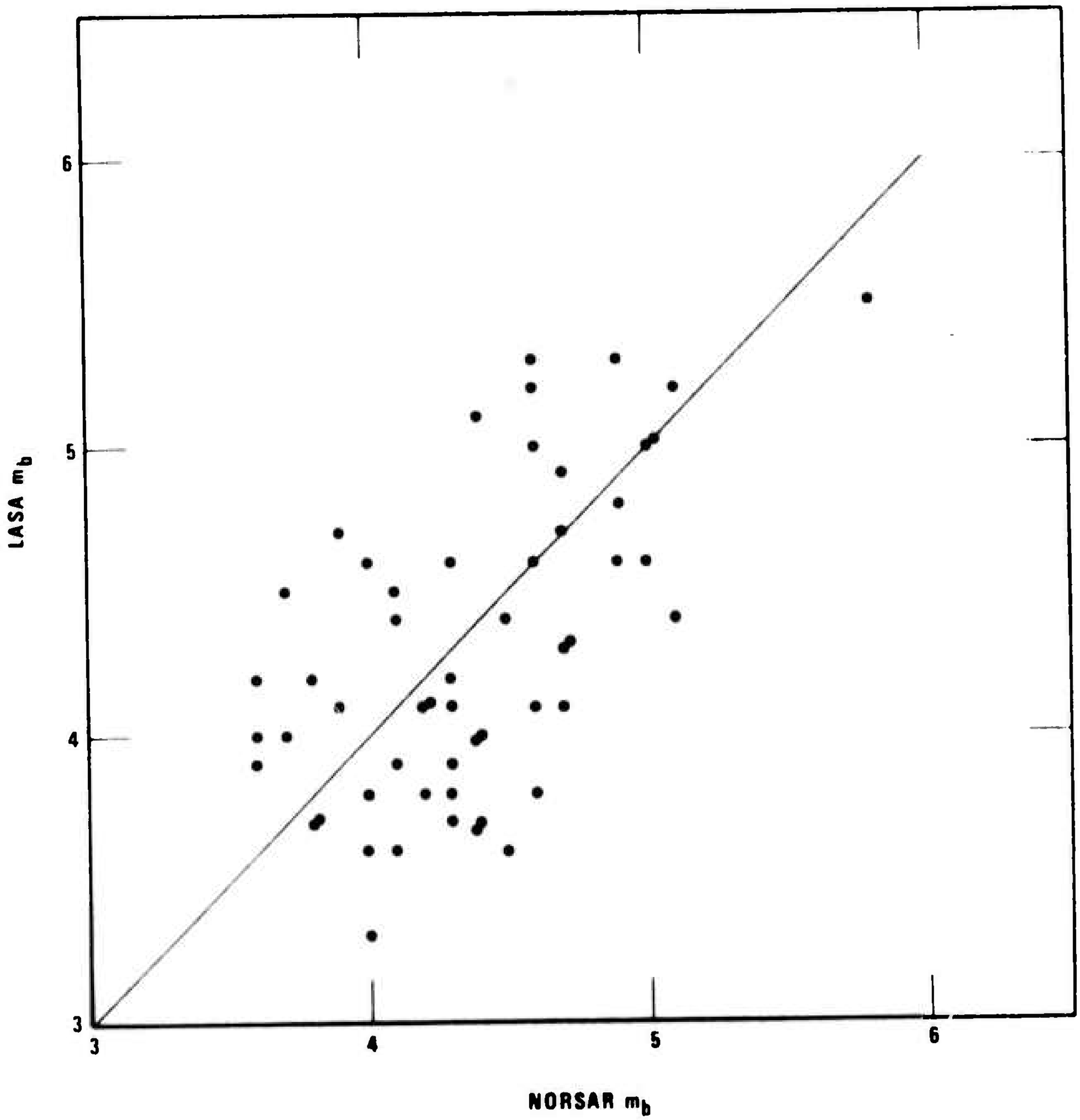


Figure 11. LASA-NORSAR m_b comparison - Kurile region.

5. CONCLUSIONS

1. The average LTA noise background of LASA's DP beams is 0.06 mμ and the average LTA noise of NORSAR's is 0.14 mμ. Since NORSAR's noise background is approximately twice that of LASA's, the detection threshold of NORSAR might be at least 0.3 magnitude units higher than that of LASA, if signal losses are comparable.

2. Diurnal variations of noise are observed in both LASA and NORSAR, and they are approximately 0.02 mμ in filtered beams.

3. Key parameters in Detection Processors are those of consecutive testing of signal-to-noise ratio, Q/Q', and consecutive testing of spatial coherency of the signal, P. In LASA these parameters are Q/Q' = 3/3 and P = 4. The DP recurrence curve suggests that a parameter of 1/1 may cause a large number of false alarms. On the other hand, Q/Q' = 3/3 in LASA causes higher LTA values, because some signals are averaged into the LTA measurements.

4. Approximately 12% of the detected signals are published at LASA and NORSAR. For example, average daily detections at LASA amount to 250, but only 30 events are published. Similarly, at NORSAR, average daily detections amount to 120, but the average event processing rate is 15.

5. About 37% of the events on the PDE list were confirmed by both LASA and NORSAR. In the mutual event

confirmation, LASA EP confirmed 70% of NORSAR EP; LASA DP confirmed an additional 11.8%; 7.2% failed LASA DP detections; and 11.1% were attributed to system failure. Similarly, NORSAR EP confirmed 38% of LASA EP; NORSAR DP confirmed an additional 12.4%; 44.7% failed NORSAR DP detections; and 4.9% were attributed to system failures.

6. Some events were missed by NORSAR's DP. These events can be grouped in several regions, indicating that either travel time residuals for these regions are not adequately compensated for at NORSAR, or amplitude anomalies caused failures to detect signals from these areas.

7. A mutual assistance plan should be created for LASA and NORSAR. At NORSAR approximately two additional events a day may be processed from DP detections simply by referring to LASA daily Event Summaries. For LASA, 46 events that had failed EP threshold were detected at NORSAR. LASA EP re-runs confirmed 14 of them, meaning an average of one event every three days may be added by consulting NORSAR Event Summaries. Many of LASA's published events are not detected by NORSAR's DP, although they are in its surveillance range. A mutual assistance algorithm may improve NORSAR simply by submitting these events for re-runs.

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ACKNOWLEDGEMENT

The author is grateful to Drs. W. C. Dean, R. R. Blandford, and Mr. R. O. Ahner for many valuable discussions; and Mr. P. F. Skeffington for programming assistances.